WYOMING FIELD CANDIDATE SCREENING FOR ENHANCED OIL RECOVERY

Final Project Report

PETE 4735 – Petroleum Engineering Design II
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Executive Summary

This report provides an analysis and evaluation of the best Wyoming field candidates for Enhanced Oil Recovery. The methods of analysis include original oil in place calculations, data screening, field and EOR pairing, production decline curve analysis, and an economic analysis. The economic analysis provides net present value, internal rate of return and net payback. The results of our analysis showed that CO_2 flooding is the most preferential EOR method in Wyoming, and that ASP is a new and plausible EOR method, but more ASP research and field trials are needed. The best fields in Wyoming tended to be sandstone, with a large net pay and small productive area. EOR is expensive, and at current oil prices there is no economic EOR oil field project in Wyoming. The report finds that the there are several EOR field prospects in Wyoming, the majority being best fit for CO_2 flooding. In order for an EOR project to be economical it requires a large OOIP and net pay, and a small productive area. The weaknesses for an EOR project are large productive areas and lack of infrastructure. The top 5 fields with great potential for EOR have been identified in this report.

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Nomenclature

EOR	Enhanced Oil Recovery
EORI	Enhanced Oil Recovery Institute
OOIP	Original Oil in Place
CO2	Carbon Dioxide
ASP	Alkaline Surfactant Polymer
NPV	Net Present Value
IRR	Internal Rate of Return
mD	Millidarcy
cP	Centipoise
bbl	Barrel
STB	Stock Tank Barrel
WTI	West Texas Intermediate

1. Introduction

In 2014, The United States consumed an average of 19 million barrels of oil per day [1], an increase of 5.5% over 2013 [2]. Year over year energy consumption is increasing, fueling the requirement for increased innovation and efficiencies to extract hydrocarbons economically. Wyoming is particularity interested in Enhanced Oil Recovery (EOR) methods to increase production from aging fields in an attempt to meet national and global demand as there is an estimated billion barrels of oil in reserves [3]. Figure 1 demonstrates how the production has decreased from a peak in the 1980's, to a trough in the early to mid-2000's. Currently, approximately 12% of the oil production in the state is produced through EOR projects.

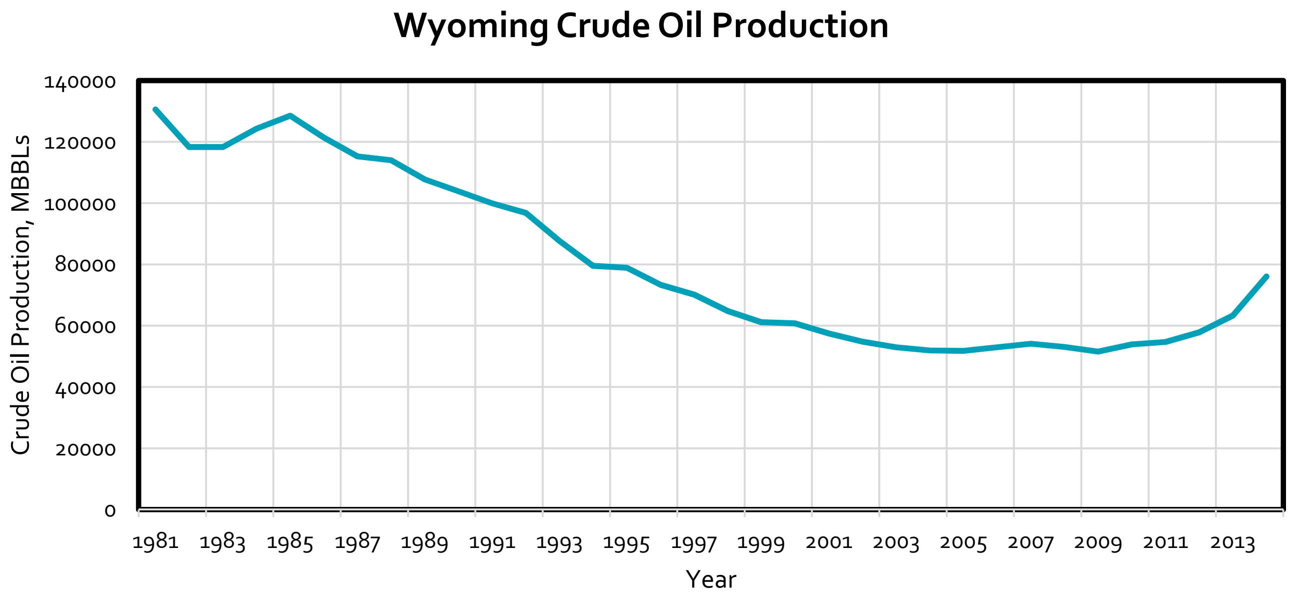


Figure 1- Wyoming Crude Oil Production

Various EOR methods exist and are potentially suitable for use in Wyoming's aging fields, most notably: carbon dioxide (CO_2) flooding, and alkaline surfactant polymers (ASP). Each method involves injecting fluids into the reservoirs in order to increase production. CO_2 flooding is particularly attractive in Wyoming because large sources of CO_2 are present throughout the state in the form of coal fired power plants and gas processing facilities. Furthermore, an existing and improving network of CO_2 pipelines exists throughout the state. These factors in conjunction with the formerly prolific depleted oil fields in the state combine for potentially high quality EOR projects at favorable commodity prices. ASP methods are also of great interest as the process promises great potential and is seen as more cost effective than traditional enhanced water flooding methods. Furthermore, ASP EOR designs represent a natural transition from secondary recovery (ie water flooding), to tertiary recovery. In this case, enhanced water flooding.

Extensive screening processes are necessary to narrow the scope of investigation as EOR processes are capital intensive, complex, and are not applicable to every field or reservoir type. Because Wyoming has various structural areas that produce hydrocarbons differently, both in terms of hydrocarbon type and recovery methods, it is important to break up the candidates in order to isolate the best oil fields and best corresponding EOR methods. An analysis of the hydrocarbon, geological, and historical properties will allow an optimal EOR/field pairing. Using the historical field production and current stage (primary, secondary, or tertiary) allows for an original oil in place (OOIP) calculation for the field. Combining the field's OOIP, age, size, EOR compatibility, accessibility, and basic economics allows the top ranked fields to be compared to one another.

For this particular project, a study of data compiled from 4867 oil & gas wells in Wyoming was conducted to establish the top five fields that demonstrate the maximum potential for future EOR methods. These candidate fields have been ranked using scorecards where criteria is given a weight based on how that reservoir conditions will be affected by each potential EOR method. Since this project will involve several different EOR processes, which may vary widely in cost, it will be necessary to simultaneously complete economic modelling in order to best represent the findings of the overall screening process.

This project has been conducted in several phases to evaluate, rank, and establish top fields candidates with analysis of the best EOR methods conducted on the corresponding candidates. The wells from this project are in Wyoming, covering over 90,000 mi^2, and have thus been broken down into ten separate structural areas due to the hydrocarbon and geologic diversity. Figure 2 is the structural map of Wyoming, and will provide the framework for which the data will be sorted. The EOR methods that have been considered include: gas injection, enhanced water flooding and thermal/mechanical methods. The criterion used for pairing fields with EOR methods, as well as ranking the field/EOR pairs, includes:

production (by volume), porosity, permeability, depth, net pay, density and viscosity. The screening project has been broken into 3 main phases: EOR database investigation and evaluation, field EOR ranking, and establishing and modelling top candidates.

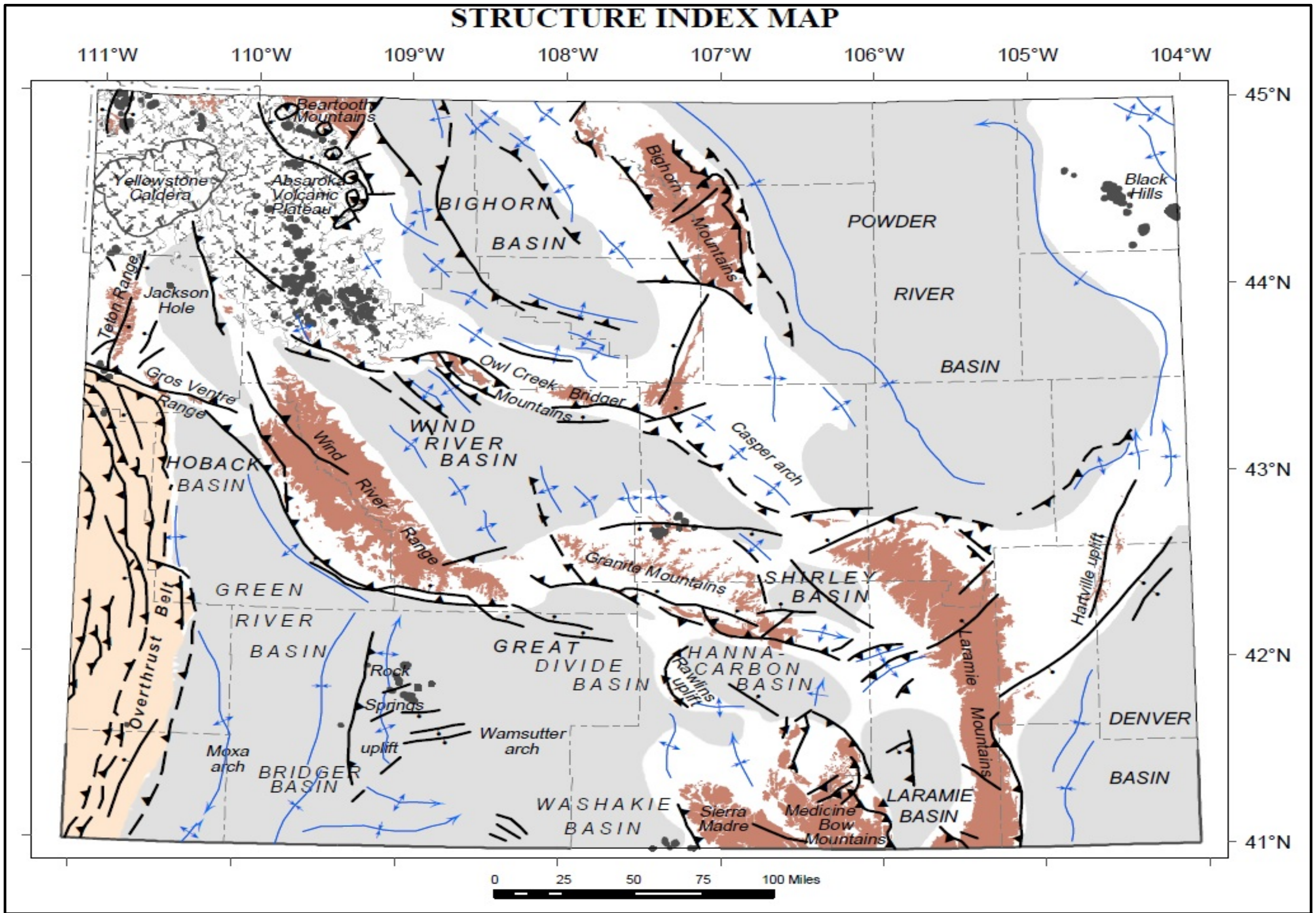


Figure 2 - Structural Map of Wyoming [4]

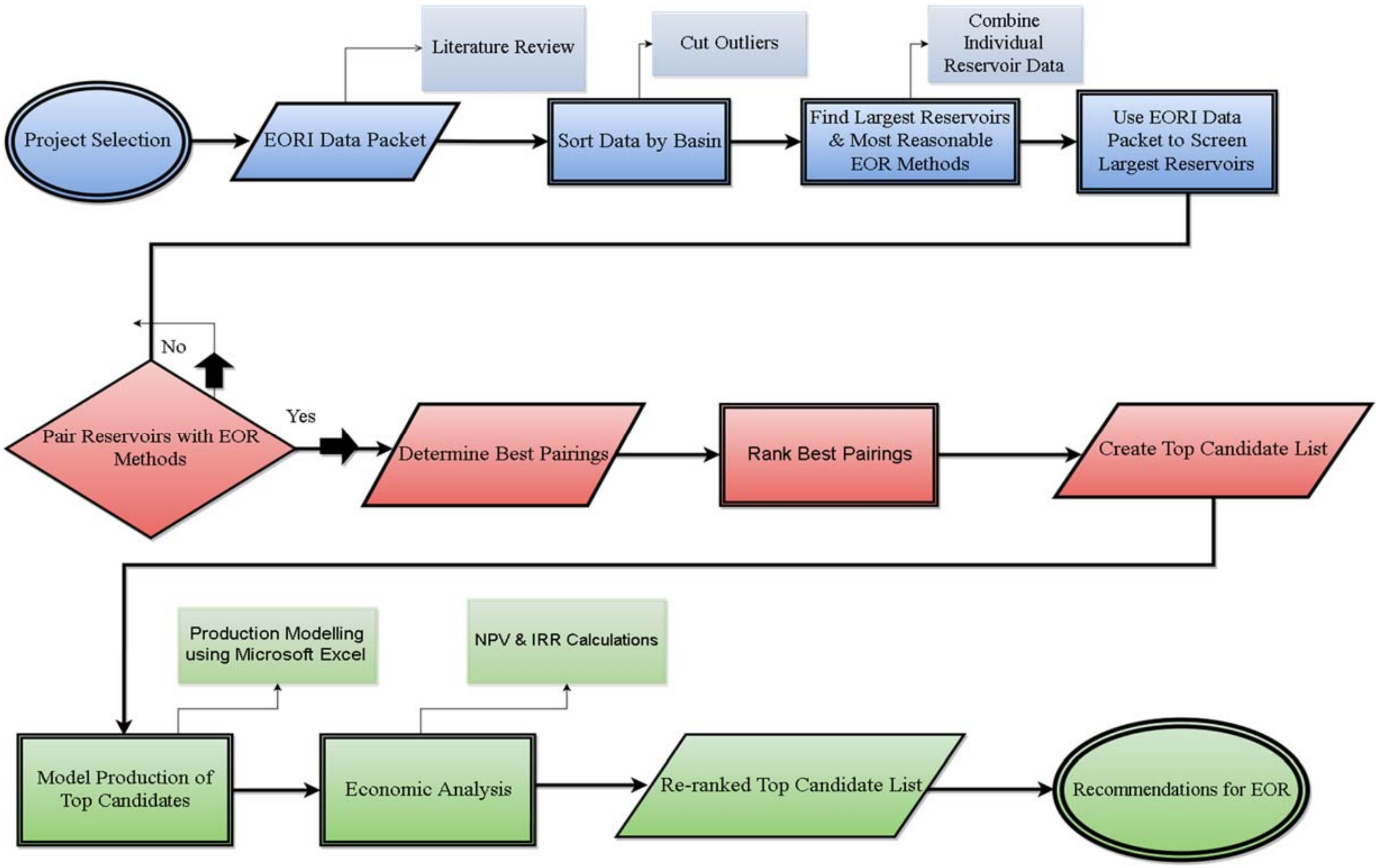
2. Project Workflow

For large projects, it is essential to have a detailed workflow in order to break down complicated processes into manageable portions. Figure 2 is a work flow specific to this project which outlines the necessary steps from data acquisition through to the final top fields selected for EOR. The work flow is broken into three phases which are to be conducted sequentially.

Phase I, in blue, of the Wyoming Field Candidate Screening for Enhanced Oil Recovery project starts obtaining the EORI well database. This database was organized by basin. Ten different basins had been identified in Wyoming. The well data was screened to ensure all data points that will be used are valid, this step ensured that the project was as accurate as possible. Once the data had been screened, the top producing reservoirs in Wyoming were identified. Using the cumulative oil production values, the OOIP was calculated for all of the top producing reservoirs. With the top reservoirs identified, the first screening took place using the EORI well database. Top reservoirs with insufficient values in the EORI data packet were eliminated from the project going forward.

Phase II, in red, began with matching each reservoir with the optimal EOR method, this was done using the geology and reservoir properties obtained from the EORI data package. The reservoir and EOR pairings were then ranked and a top candidate list was created. The pairings were ranked based on the calculated OOIP volumes, where the larger the OOIP the higher it was on the list.

Phase III, in green, started with a production analysis for the top candidates. A decline curve analysis was done, which was required for the economic analysis. The economic analysis is essential to the project because the EOR method and reservoir pairings could vary widely in cost and expected production. The analysis will allow a new and more scientific re-ranked candidate list. Using economic models, we were able to calculate the NPV, IRR and net payback for our pairings. A final re-ranking of our top candidate list was done. With the re-ranked candidate list finished, final recommendations were made for the top 5 candidates.



🟦	Phase I
🟥	Phase II
🟩	Phase III

Figure 3 - EOR Field Screening Workflow

3. Phase I: EOR Database Investigation & Evaluation

The EORI is capable of delivering large Microsoft Excel raw data packages, which require significant sorting and analysis. With over 90,000 cells of data, it has been important to focus on organization and efficiency when dealing with such a large data pool. The first efforts made with the data were all focused on organization which included dividing the data by structural areas and cutting outliers based on lack of supporting data.

The data package given contained 4867 specific field-reservoir pairs in Wyoming. These pairs contained geology and reservoir data. With the basal information obtained from the data packet, the next step was to look for the best potential reservoirs to focus on. An intensive literature review was done to find the top producing reservoirs in Wyoming. The top producing reservoirs list was compiled and the OOIP's were calculated based on the production history, which was available from the Wyoming Oil and Gas Conservation Commission. The focus on OOIP came from the expectation that for a good recommendation to be made the field had to be a good producer. Once the top OOIP list had been compiled, the reservoirs were then cross checked with the EORI data package. The reservoirs with insufficient data in the EORI package were eliminated from contention.

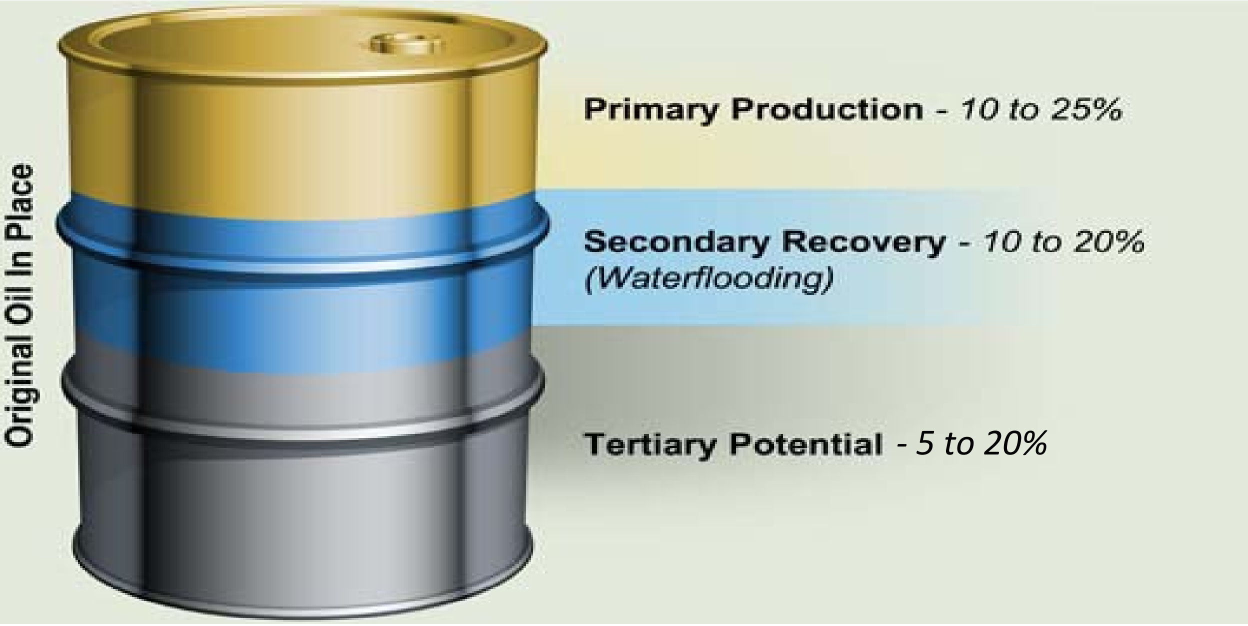


Figure 5 – Reservoir Recovery Percentages

Fig 1. Production Recoveries to Calculate OOIP

As seen in Fig 1, production values can be assumed in order to calculate OOIP. If a reservoir is in its primary stage of production it has recovered approximately 10% of its OOIP. If a field is in its secondary stage of production it has recovered approximately of 25% of its OOIP. Tertiary recovery ranges from an additional 5-20%, but since the recovery was based on the EOR method used this range was not applicable in the calculations.

Table 1: Candidate Field List based on OOIP

Field	**OOIP (MM STB)**
Oregon Basin	845
Frannie	440
Hartzog Draw	439
Lost Soldier	410
Elk Basin	341
Hamilton Dome	311
Garland	303
Grass Creek	237
Brady	223
Wertz	187

Table 1 lists the fields in Wyoming that had the highest OOIP using our production based OOIP calculations and the data crosschecking using the EORI data package. This was the initial list of candidates of fields for which an EOR method would paired. Before any matching with EOR methods was done, the list was screened. This screening of our data was to determine whether the reservoirs in the top fields were already undergoing and EOR. The fields that are highlighted in red have already undergone EOR, so they were taken from our list of top candidates. This screening method continued until we had a new candidate list, where we then paired the top reservoirs with the best EOR methods. This list will be shown later in the report.

Table 2: Summary of Screening Criteria for EOR Methods

EOR Method	Gravity (API)	Viscosity (cp)	Porosity (%)	Permeability (md)	Depth (ft)	Temperature (F)
Miscible Gas Injection						
CO2	28 – 45	35 – 0	3 – 37	1.5 – 4500	1500 – 13365	82 – 250
Hydrocarbon	23 – 57	18000 – 0.04	4.25 – 45	0.1 – 5000	4040 – 15900	85 – 329
Immiscible Gas Injection						
Hydrocarbon + WAG	9.3 – 41	16000 – 0.17	18 – 31.9	100 – 6600	2650 – 9199	131 – 267
Nitrogen	16 – 54	18000 – 0	11-28	3 – 2800	1700 – 18500	82 – 325
CO2	11 – 35	592 – 0.6	17 – 32	30 – 1000	150 – 8500	82 – 198
(**Enhanced) Water Flooding**						
Polymer	13 – 42.5	4000 – 0.4	10.4 – 33	1.8 – 5500	700 – 9460	74 – 237.2
Alkaline Surfactant Polymer	23 – 34	6500 – 11	26 – 32	596 – 1520	2723 – 3900	118 – 158

Table 2 was used to find the reservoir and geology properties that would fit an EOR method to a reservoir. With this information, the project moved forward into more literature review into EOR methods and how would they best fit the top reservoirs in Wyoming. The EOR methods that had the most potential towards the reservoirs and fields in Wyoming were miscible CO2 and ASP.

CO2 had high potential as a good EOR method to be used in Wyoming. Based on literature review, there have been many fields in Wyoming that fit the technical criteria for CO2. Aside from many possible candidates, there have already been projects done using this EOR method. For example Lost Soldier and Wertz fields have already undergone CO2 injection. There is also major CO2 infrastructure already in place. There is the LaBarge Plant in Shute Creek and the Conoco Phillips Plant in Lost Cabin, these plants produce CO2. There are also CO2 pipelines which are accessible to Wyoming's oil fields, such as the Greencore pipeline which passes through the Powder River Basin.

ASP also had high potential as an EOR method in Wyoming. ASP has been researched to make oil recovery increase in a short amount of time. This method is good for shallow fields, and sandstone reservoirs of which there are many in Wyoming. The cost of ASP is also purported to be fairly low, lower than the similar EOR method, surfactant polymer.

4. Phase II: Field EOR Pairing & Ranking

The next step of our project was identifying which reservoirs and fields have the greatest potential for matching EOR processes. In order to estimate the production and economics, it was necessary to match our given well data with the top EOR method. The pairing process was based on the geology and reservoir properties in the EORI data package and the EOR suitability requirements based on the literature review. The major task in this phase was pairing. We paired all of the top reservoirs with the better of the two EOR methods we had chosen: CO2 and ASP.

Here is an example that shows how we paired the EOR methods with the reservoirs. Table 1 is the EOR suitability requirement table. The reservoir properties should be in the required range for one type of EOR method listed in this table in order for them to be paired. Table 2 contains the properties of the Shannon reservoir in the Hartzog Draw field. It is obvious that all the properties of the Shannon reservoir are in the required range for CO2 injection. When looking at the ASP injection method, we found that the permeability and the API gravity of Shannon in the Hartzog Draw field are out of the required range. So the Hartzog Draw field is a good candidate of CO2 injection, instead of ASP.

5. Phase III: Modelling & Establishing Top Candidates

Field rankings based on economic analysis were made based on three factors, the net present value (NPV) of each field, net payback period, and ultimately internal rate of return (IRR) after the EOR method application. Net present value has been consistently used in the industry to evaluate projects and investments as the calculation compares the amount invested today to the present value of the future cash receipts from the investment. For that, we have considered the net cash flow models as a suitable method since it is able to include all costs variables and provide us an accurate value proposition for our rankings. Meanwhile net payback period allowed us to look at our length of investment against our net present value to see whether it might be a worthwhile investment. The internal rate of return is commonly used in capital budgeting measuring the profitability of potential investments.

Our economic analysis was been purely focused on ASP and CO2 methods, as those two were the only pairings we had in our top 10 field rankings. Costs of using either one of the methods varied greatly. After our literature review we were able to come up with the cost estimates from similar fields in Wyoming.

5.1. Production Modelling

Our top candidate list contained the reservoir/EOR pairings with the highest calculated OOIP. The next step of our project was to further analyze the top candidates, then re-rank the top candidates before doing a production analysis. Our re-ranking was done by looking at several main factors: age of the field, stage of production, cumulative reservoir production to date, reservoir OOIP, reservoir production rate, and multiple top candidate reservoirs within the same field. With all of these factors it was possible to re-rank our top candidate list.

Analyzing the monthly production values for each field was important. The monthly production values were used to calculate the decline rates for the top candidates. The decline rates were used in order to more accurately predict the incremental production increases for a field under a particular EOR process.

The monthly production increases are important to know for several reasons, one of which being the cash flow statements generated by the projects.

5.2. Economic Modelling

Our economic modelling was done using the CO2 scoping tool, provided by Dr. Ben Cook from the EORI. The tool used dozens of inputs in order to generate all of the required numbers and figures required for our final re-ranking. Specifically it gave us the IRR, NPV and net payback. Typically, a company will not go forwards with a large, and capital intensive, project if the IRR is less than 20%. In other words, a project could technically economic as the NPV is greater than zero, but the IRR is less than the company's set value of 20% so the project does not move forwards. For each of the candidates analyzed in Phase III, the NPV, payback period, and IRR were calculated.

Our economic analysis focused on ASP and CO_2 methods as those two were the only pairings in the top 10 field rankings. Costs of using either one of the methods vary greatly. After our literature review we were able to develop the cost estimates from similar projects in Wyoming.

5.2.1 CO2 Injection Economics

A CO_2-EOR project requires a large capital investment, especially to drill new wells, set up surface production, CO2 separation, recycling, and compression facilities. However, Wyoming is one of only 10 states to have CO2 gas pipelines or gas processing plants. The LaBarge Shute Creek Natural Gas Processing plant caters to most of the southwest fields in Wyoming while the newly developed Greencore pipeline supplies the central region. This has made the decreased the cost of CO2 transportation in Wyoming. Figure 6 is a map of Wyoming with the large CO_2 emitting plants, and CO_2 pipelines overlaid.

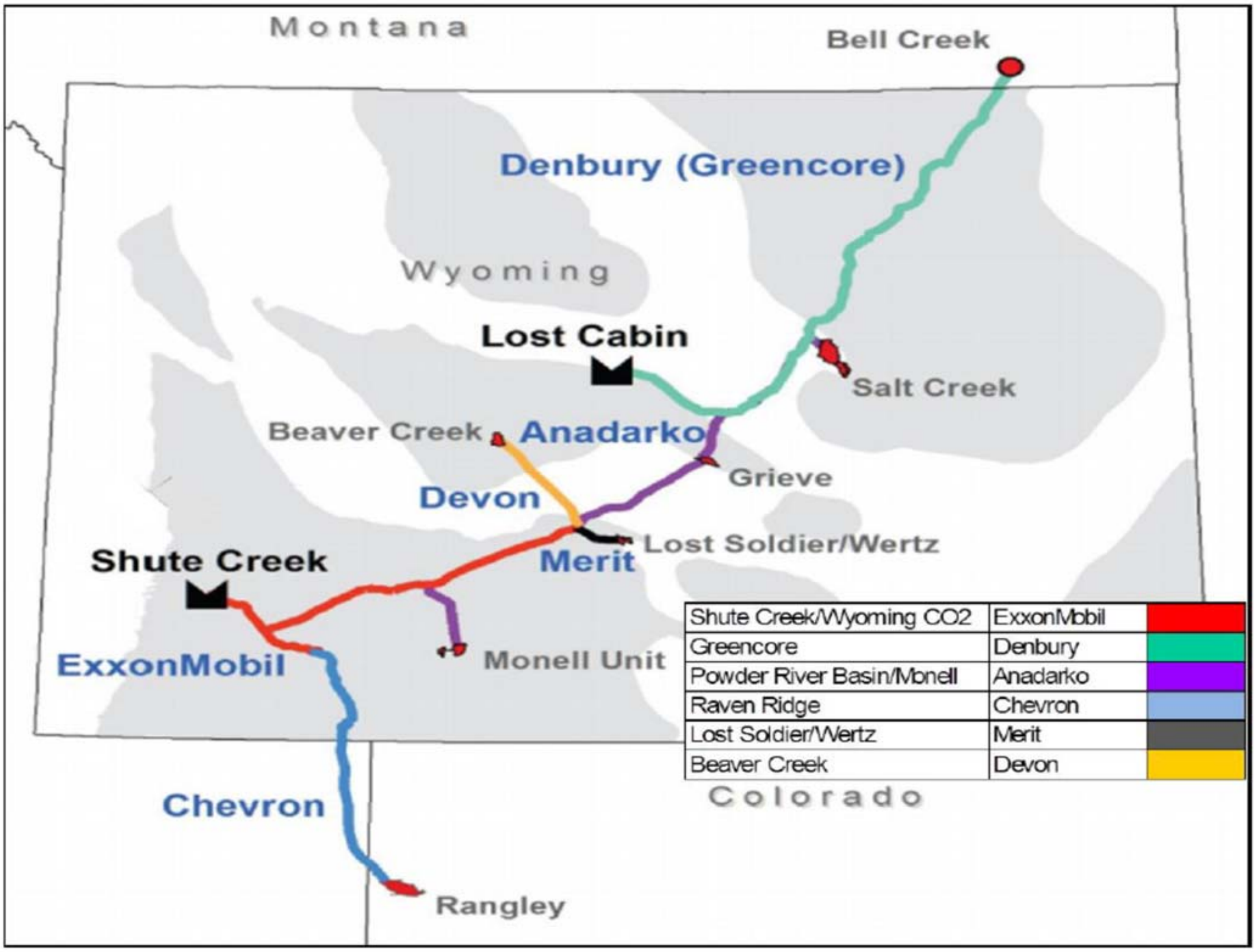
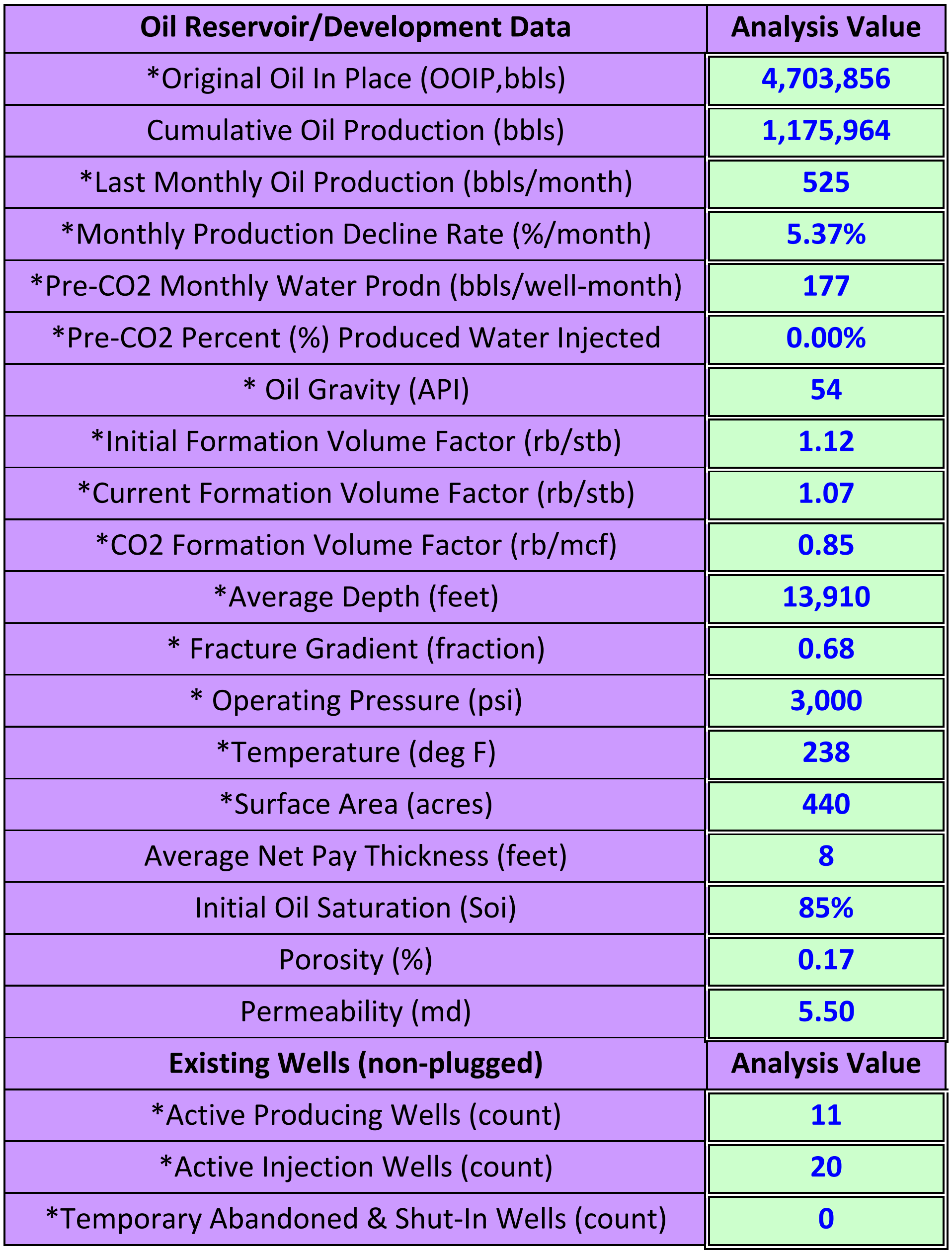


Figure 6 – Wyoming CO2 Infrastructure

To fully model the economics of each project, the CO_2 Scoping tool developed by Dr. Ben Cook and Dr. Klass van't Veld of the EORI was used. This tool was extremely helpful and allowed for a comprehensive analysis of each field. The tool allows the user to input variables ranging from reservoir properties, production history, commodity prices, CO2 project design parameters, taxing values and other field information then outputs the economics for the project in question. To model the economics of the user defined project, the tool uses previously conducted CO_2 projects in the country to model incremental production increases and the anticipated production for the field. Using that production information, the cash flows are generated while considering the taxing and royalty parameters, estimates for infrastructure requirements, new wells which will need to be drilled, commodity prices and discounts based on crude type and API, and other design factors.



Oil Reservoir/Development Data	Analysis Value
*Original Oil In Place (OOIP,bbls)	4,703,856
Cumulative Oil Production (bbls)	1,175,964
*Last Monthly Oil Production (bbls/month)	525
*Monthly Production Decline Rate (%/month)	5.37%
*Pre-CO2 Monthly Water Prodn (bbls/well-month)	177
*Pre-CO2 Percent (%) Produced Water Injected	0.00%
* Oil Gravity (API)	54
*Initial Formation Volume Factor (rb/stb)	1.12
*Current Formation Volume Factor (rb/stb)	1.07
*CO2 Formation Volume Factor (rb/mcf)	0.85
*Average Depth (feet)	13,910
* Fracture Gradient (fraction)	0.68
* Operating Pressure (psi)	3,000
*Temperature (deg F)	238
*Surface Area (acres)	440
Average Net Pay Thickness (feet)	8
Initial Oil Saturation (Soi)	85%
Porosity (%)	0.17
Permeability (md)	5.50
Existing Wells (non-plugged)	**Analysis Value**
*Active Producing Wells (count)	11
*Active Injection Wells (count)	20
*Temporary Abandoned & Shut-In Wells (count)	0

Figure 7 – CO2 Scoping Tool

As this project does not deal with specific EOR design requirements, the team elected to simplify the inputs and use conservative values for the recovery factor expected for the project. Figure 7 is a snapshot of the input area in the tool.

The CO_2 Scoping tool was used for the top 10 CO_2 candidates, and based on the economics, the top 5 candidates were selected. The projects were evaluated at single market value price. This price was a West Texas Intermediate (WTI) value of $80/bbl. This was the chosen oil price in order to show some of the projects with IRR's over 20%. Table 6 summarizes the top 5 CO2 candidates which will be further analyzed in the following sections.

Table 6: Summary of Top 5 EOR Candidates

Rank	Field	Formation	NPV (MM$$)	Payback Period (years)	IRR (%)	Break Even ($/STB)
1	Frannie	Tensleep	540	5	24.48	58
2	Brady	Nugget	487	5	23.86	60
3	Finn-Shurley	Turner	135	7	11.33	71
4	Steamboat Butte	Tensleep	6	3	.93	79
5	Hartzog Draw	Shannon	-191	-	-	85

It should be noted that the IRR and payback period for Hartzog Draw were not included because the project would not be economic with oil at a WTI of $80/bbl.

5.2.1.1 Frannie-Tensleep Analysis

Based on the economic analysis, the Tensleep formation in the Frannie field rated out as the top CO_2 EOR candidate. Table 7 summarize the geological and reservoir properties for the field.

Table 7: Summary of Frannie Geological, Reservoir, and Economics

Geological Properties	
Matrix	Sandstone
Production Area (acres)	1,700
Depth (ft)	3,400
Net Pay Thickness (ft)	100
Reservoir Properties	
OOIP (MM STB)	440

Porosity (%)	17
Permeability (mD)	75
Temperature (^{0}F)	96
Oil Gravity (^{0}API)	28
Viscosity (cP)	17.25
Economics (at WTI of $80/STB)	
NPV (MM$)	540
IRR (%)	24.48
Payback Period (years)	4
Breakeven ($/STB)	58

The Frannie field offers several desirable CO_2 EOR features. Aside for the solid CO2 EOR capability, the OOIP of the Tensleep formation is very large. Furthermore, the field has been well developed and covers a relatively small production area compared to the net pay thickness, so the CO_2 scoping tool estimated there wouldn't be a requirement to drill new wells. The existing well pattern could be designed to change some producers to injectors, and use the current injectors in the flooding strategy. However, a more specific design could change those assumptions.

There are two large detractors for the project. Firstly, the Frannie field is located a great distance from any CO_2 infrastructure. Fortunately, the CO_2 scoping tool is able to incorporate the costs for constructing a CO2 pipeline to the desired area. To be safe, we chose a 200 mile pipeline requirement. The second large detractor to this field, is the quality of crude produced. At an API of 28^0, the product is worth less than higher quality crude.

Overall, this field has very high potential for CO2 EOR projects and should be researched more thoroughly.

5.2.1.2 Brady-Nugget Analysis

Based on the economic analysis, the Nugget formation in the Brady field rated out as the second CO_2 EOR candidate. Table 8 summarize the geological and reservoir properties for the field.

Table 8: Summary of Brady Geological, Reservoir, and Economics

Geological Properties	
Matrix	Sandstone
Production Area (acres)	737
Depth (ft)	11,900
Net Pay Thickness (ft)	118
Reservoir Properties	
OOIP (MM STB)	107
Porosity (%)	11

Permeability (mD)	23.2
Temperature (^{0}F)	218
Oil Gravity (^{0}API)	48
Viscosity (cP)	5.89
Economics (at WTI of $80/STB)	
NPV (MM$)	487
IRR (%)	23.86
Payback Period (years)	5
Breakeven ($/STB)	60

The Brady field offers several desirable CO_2 EOR features. Aside for the solid CO_2 EOR capability, the OOIP of the Nugget formation is very large. Furthermore, the field covers a relatively small production area compared to the net pay thickness, so the CO_2 scoping tool estimated there wouldn't be a requirement to drill new wells. The existing well pattern could be designed to change some producers to injectors, and use the current injectors in the flooding strategy. However, a more specific design could change those assumptions. Additionally, the quality of crude in the field is very high, thus resulting in a higher attainable commodity price as compared to many of the other fields which were analyzed. The Brady field is also located in a very favorable location for CO_2 projects. As the field is very close to the Lost Soldier-Wertz CO_2 projects, much of the CO_2 transportation infrastructure is located close by (10-15 miles).

Overall, this field has very high potential for CO_2 EOR projects and should be researched more thoroughly.

5.2.1.3 Finn-Shurley-Turner Analysis

Based on the economic analysis, the Turner formation in the Finn-Shurley field rated out as the third CO_2 EOR candidate. Table 9 summarize the geological and reservoir properties for the field.

Table 9: Summary of Finn-Shurley Geological, Reservoir, and Economics

Geological Properties	
Matrix	Sandstone
Production Area (acres)	1,300
Depth (ft)	4,926
Net Pay Thickness (ft)	27
Reservoir Properties	
OOIP (MM STB)	114
Porosity (%)	12

Permeability (mD)	11
Temperature (^{0}F)	123
Oil Gravity (^{0}API)	41
Economics (at WTI of $80/STB)	
NPV (MM$)	135
IRR (%)	11.33
Payback Period (years)	7

Finn-Shurley has some attractive reservoir and geology properties. The API gravity is 41°, which has the potential to increase the amount of money received for every barrel of oil produced. The reservoir is not relatively deep, so drilling costs could be lower than other candidates. However, Finn-Shurley has some unattractive properties as well. A low net pay and larger productive area will require larger infrastructure in order to produce oil using EOR. The Finn-Shurley field is also one of the fields that is furthest from any CO2 pipeline infrastructure, ~75 miles, which is unfavorable due to high costs of constructing a pipeline.

5.2.1.4 Steamboat Butte-Tensleep Analysis

Based on the economic analysis, the Tensleep formation in the Steamboat Butte field rated out as the fourth CO_2 EOR candidate. Table 10 summarize the geological and reservoir properties for the field.

Table 10 – Summary of Steamboat Butte Geological, Reservoir, and Economics

Geological Properties	
Matrix	Sandstone
Production Area (acres)	1,600
Depth (ft)	5,320
Net Pay Thickness (ft)	200
Reservoir Properties	
OOIP (MM STB)	67
Porosity (%)	12
Permeability (mD)	41
Temperature (^{0}F)	131
Oil Gravity (^{0}API)	28
Viscosity (cP)	
Economics (at WTI of $80/STB)	
NPV (MM$)	6

IRR (%)	0.93
Payback Period (years)	3

Steamboat Butte had a medium to large production area and a shallower depth. It has a very large net pay, making it very attractive as a potentially good producer. It is also fairly close to the Pavillion Gas Plant, which would reduce infrastructure costs.

5.2.1.5 Hartzog Draw-Shannon Field Analysis

Based on the economic analysis, the Shannon formation in the Hartzog Draw field rated out as the fifth CO_2 EOR candidate. Table 11 summarize the geological and reservoir properties for the field.

Table 11 – Summary of Hartzog Draw Geological, Reservoir, and Economics

Geological Properties	
Matrix	Sandstone
Production Area (acres)	31,065
Depth (ft)	12,021
Net Pay Thickness (ft)	20
Reservoir Properties	
OOIP (MM STB)	439
Porosity (%)	12
Permeability (mD)	12
Temperature (^{0}F)	194
Oil Gravity (^{0}API)	37
Viscosity (cP)	1.22
Economics (at WTI of $80/STB)	
NPV (MM$)	-191
IRR (%)	-
Payback Period (years)	-
Breakeven ($/STB)	85

Hartzog Draw was previously ranked as our top candidate due to its high OOIP. After our analysis however, it was found that there are several factors that make the Hartzog Draw field a poor choice for EOR. Firstly, the productive area was by far the largest that was seen at over 30,000 acres. This large productive area would require over 400 new wells be drilled in order to fill the need of CO2 injection wells. The net pay is also relatively poor. The field is located very close to CO2 infrastrucutre, but this did not make up for the previously mentioned unfavorable factors.

5.2.2 ASP Flood Economics

Though data were scarce on ASP-EOR method, we were able to find two ASP projects done in Wyoming in West Kiehl Field and Tanner Field, Table 8.

Table 12: Economic Parameters Summary of West Kiehl and Tanner Fields

	West Kiehl Field	**Tanner Field**
Year ASP project began	1987	2000
Total chemical and plant costs ($)	611,064	1,430,000
Operating Costs ($/month)	12,200	N/A
Projected costs per incremental barrel of oil ($)	2.13	5.85

The average cost of chemical has reduced to an average of $2.75/bbl compared to $11.50/bbl in the 1980's due to advancements in the process of formulating the ASP according to surfactants producer Oil Chem Technologies. We have chosen the data provided in the Tanner Field case study as it is more recent and more comparable to the current oil climate. Assuming the lower chemical cost has offset inflation adjusted plant construction costs, we will continue using $1,430,000 as a suitable value for current considerations. While the operating costs for Tanner field when adjusted to inflation from the data from West Kiehl field would be $16,871.14.

Data was not available for ASP CAPEX. Assuming it would require a similar setup to CO2-EOR method, we can remove some cost items and be able to calculate the remaining CAPEX costs as shown in Table 9.

Table 13 – ASP CAPEX Costs

Cost Item	Cost ($)	Total cost ($) assuming average depth of well is 2500ft
Total chemical and plant costs	1,430,000	1,430,000
Drilling of new well	333/ft	832,500
Working over and equipping existing producing well	231,980 per well	231,980
Equipping a new producer	570,847 per well + 35/ft	658,347
Preparing well for injection	257,866 + 35/ft	345,366
Total CAPEX		**3,498,193**

5.2.2.1 Hamilton Dome-Tensleep Analysis

Based on the economic analysis, the Tensleep formation in the Hamilton Dome field rated out as the first ASP EOR candidate. Table 14 summarize the geological and reservoir properties for the field.

Table 14 – Summary of Hamilton Dome Geological, Reservoir, and Economics

Geological Properties	
Matrix	Sandstone
Production Area (acres)	1,800
Depth (ft)	3,111
Net Pay Thickness (ft)	184
Reservoir Properties	
OOIP (MM STB)	212
Porosity (%)	15
Permeability (mD)	60

Temperature (^{0}F)	135
Oil Gravity (^{0}API)	21
Viscosity (cP)	63
Economics (at WTI of $80/STB)	
NPV (MM$)	14
IRR (%)	28
Payback Period (years)	2

Our best matching ASP-EOR method was Hamilton Dome – Tensleep. The key differentiator of this field being matched with ASP rather than CO2 was viscosity and depth. Viscosity of 63 cP was very high to be considered for any other EOR methods and ASP was the only one which was within the range. Depth of 3111 ft is too shallow by industry standards for CO2 consideration thus making ASP a better fit

5.2.2.2 Pitchfork-Tensleep Analysis

Based on the economic analysis, the Tensleep formation in the Pitchfork field rated out as the Second ASP EOR candidate. Table 15 summarize the geological and reservoir properties for the field.

Table 15 – Summary of Pitchfork Geological, Reservoir, and Economics

Geological Properties	
Matrix	Sandstone
Production Area (acres)	800
Depth (ft)	4,180
Net Pay Thickness (ft)	30
Reservoir Properties	
OOIP (MM STB)	138
Porosity (%)	20
Permeability (mD)	31
Temperature (^{0}F)	121
Oil Gravity (^{0}API)	18
Viscosity (cP)	132
Economics (at WTI of $80/STB)	
NPV (MM$)	-787
IRR (%)	-
Payback Period (years)	-

Our second best ASP-EOR matching was for Pitchfork-Tensleep field. The key differentiator in this field was the high viscosity of 132 cP. At that value, it was way too high for any other EOR methods. The field size and depth which was small was a very good fit for ASP method which often favors smaller fields. Figure 9 shows the field map of Pitchfork – Tensleep.

5.2.3 Taxes

The net present value can only be calculated after taking into account all tax and royalty payments. The taxes levied upon oil and gas companies in Wyoming are shown in Table 10.

Table 16: Taxes Levied Upon Oil and Gas Companies in Wyoming

Type of taxes	Tax rates
Federal Government	12.50%
WY State Government	18.75%
Royalties to Private Parties	18.75%
Severance Tax	4.00-6.00%
Property Taxes	6.50-7.40%

Royalties to private parties only covers 27% of the leases in Wyoming and thus for standardization it will not be applied to our economic analysis. Severance and property taxes vary by county in the state of Wyoming.

6. Risk Analysis

A detailed risk analysis is always important for projects of all sizes, as projects can quickly run off track in terms of time and budgets. For an EOR screening project of this nature, where a large database is manipulated, most of the execution risks associated with the project can be assigned to the following categories: resources, scope creep, and data limitations.

6.1. Risk Identification

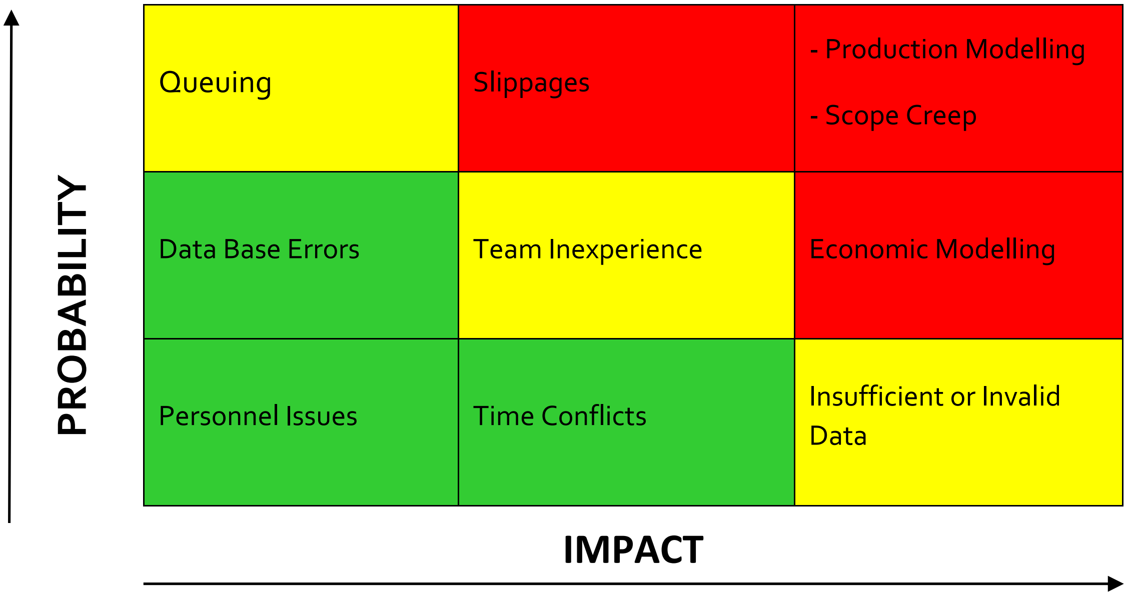
In terms of resources, because this is not a capital intensive project, the risks lie within the personnel available for the project and the data available. Most notably, the largest issues manifest as: time conflicts, fatigue, lack of motivation, queuing, data quality and availability.

Scope creep has the largest potential to run a project over budget and/or schedule. The largest issues of scope creep involve gaps or defects in the scope. Scheduling risks fall into the scope category as well because the schedule is derived from the scope. Reasonable deadlines must be set in order to achieve the objectives and deliver the recommendations to the stakeholders at the appropriate time.

Data limitations exist with respect to the database provided, as well as the production and economic data available. Extensive measures must be taken to ensure that the final recommendations use high quality data points and thoroughly researched assumptions. The consequences for using poor data and assumptions is inaccurate selections and recommendations put forth to the EORI.

6.2. Qualitative Risk Analysis

Every risk has different occurrence and impact probabilities. Risk charts are helpful to qualitatively assess the inherent risks of the project, and the following risk assessment matrix applies to the outlined risks previously mentioned.



Queuing	Slippages	- Production Modelling - Scope Creep
Data Base Errors	Team Inexperience	Economic Modelling
Personnel Issues	Time Conflicts	Insufficient or Invalid Data

Figure 8 – Qualitative Risk Analysis Matrix

The colors in the Risk Matrix figure represent progressively larger risks. Green represents minor risk, yellow represents major risks, and red represents critical risks.

6.3. Risk Monitoring and Control

Understanding how risks will be incurred and affect the project is critical for monitoring and mitigating the risks. For a project that mostly consists of database manipulation and model creation, there are several steps which can be taken to effectively mitigate the associated risks. The following strategies and tools will be used to accomplish these goals:

1) Spend first semester and winter break researching and planning:

This approach allows a team to decrease the gaps in subject matter knowledge and increase the accuracy of the scope and assumptions associated with the project.

2) Create detailed flow and Gantt charts:

A detailed flowchart helps break a large project into manageable portions, from which a Gantt chart can be created. Outlining tasks, scheduled start and end dates, and assignments are useful for mitigating any scope gaps, and personnel issues. Furthermore, a Gantt chart is extremely useful for setting reasonable deadlines, and building in buffer time for any issues which may arise throughout the projects life.

3) Set predetermined sorting techniques for data mining:

This procedure is especially important as the database will drive the data used in the following steps of the project. Firmly establishing sorting techniques through group collaboration and literature review should eliminate or drastically diminish the probability of the data mining errors.

The database has many wells where the average reservoir properties are not available. Furthermore there are many instances where only one well is producing from a specific reservoir for a field. Because it is necessary to use average reservoir properties over the field, it is not reasonable to use just one data point. Other cases exist where wells are producing out of multiple reservoirs, so the production values cannot be allocated to specific reservoirs.

7. Summary

The Enhanced Oil Recovery Institute was established by the state of Wyoming in order to help energy producers recover a large resource of stranded oil within reservoirs. Enhanced Oil Recovery is an effective tool that allows a greater volume of oil to be produced from reservoirs. It is however a very expensive tool that requires proper planning and research in order to become economic. In this project, we identified Wyoming's top producing reservoirs and calculated the OOIP. We then paired the top reservoirs with the best matched EOR methods, then ranked the pairings and created a top candidate list. The reservoirs in the top candidate list then had their production and economics modelled. This modelling allowed a final re-ranking of our top candidate and a final 5 reservoir recommendation was made.

8. Conclusions

Working with the EORI, our group was able to use production and well data to determine the top reservoirs and fields in Wyoming with the greatest potential to recover oil using EOR techniques. The top 5 fields in Wyoming that we believe hold the greatest EOR recovery potential have been identified. Production and economic analyses allowed a ranking of the top candidates based on several economic factors: IRR, NPV, and net payback. However, at current oil prices, none of our top candidates made money.

9. Recommendations

Table 17: Top Field Candidate Recommendations

Rank	Field-Reservoir	NPV, MM$	Payback, Years	IRR (@ 80$/bbl)
1	Frannie-Tensleep	540	5	24.48%
2	Brady-Nugget	487	5	23.86%
3	Finn Shurley-Turner	135	7	11.33%
4	Hamilton Dome-Tensleep	14	2	28.00%
5	Steamboat Butte-Tensleep	6	3	0.93%

Due to the increasing difficulty of producing oil, it will be necessary for oil producers in Wyoming to use EOR if they want to recover as much of Wyoming's billion barrel reserves as possible. In this project, the top Wyoming fields with EOR potential have been identified. The above table contains the final top 5 Wyoming field recommendations for EOR. Some of the factors that these reservoirs had in common were: small to medium productive areas, medium to large net pays, above average porosity, permeability and oil gravity. Poor EOR candidates tended to have very large productive areas and small net pays. These top fields show the greatest potential for economical oil recovery using EOR and should be studied in greater detail going forward for future EOR projects.

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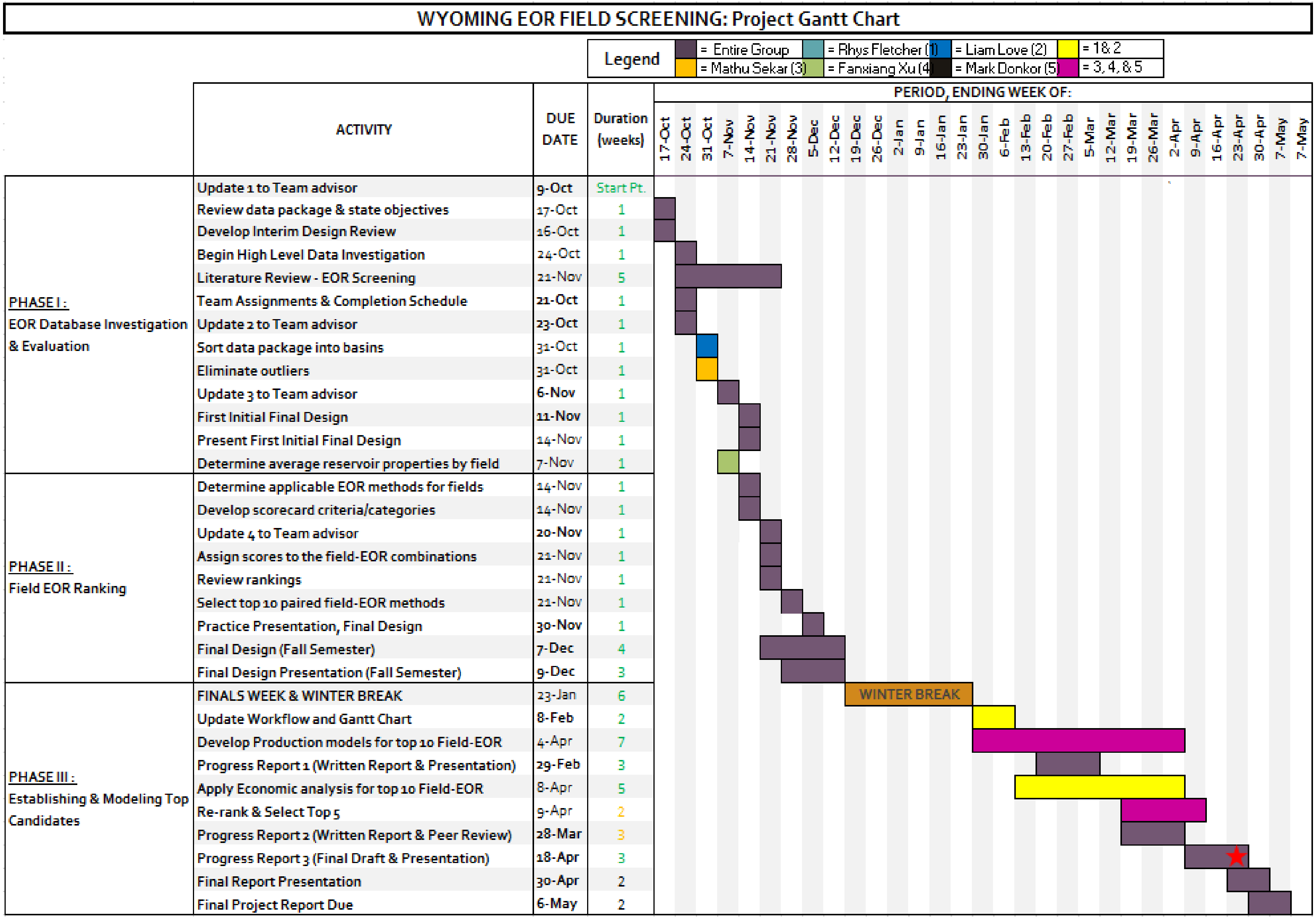
10. Appendix



WYOMING EOR FIELD SCREENING: Project Gantt Chart

Legend

■	= Entire Group	■	= Rhys Fletcher (1)	■	= Liam Love (2)	■	= 1& 2
■	= Mathu Sekar (3)	■	= Fanxiang Xu (4	■	= Mark Donkor (5)	■	= 3, 4, & 5

PERIOD, ENDING WEEK OF: 17-Oct, 24-Oct, 31-Oct, 7-Nov, 14-Nov, 21-Nov, 28-Nov, 5-Dec, 12-Dec, 19-Dec, 26-Dec, 2-Jan, 9-Jan, 16-Jan, 23-Jan, 30-Jan, 6-Feb, 13-Feb, 20-Feb, 27-Feb, 5-Mar, 12-Mar, 19-Mar, 26-Mar, 2-Apr, 9-Apr, 16-Apr, 23-Apr, 30-Apr, 7-May, 7-May

	ACTIVITY	DUE DATE	Duration (weeks)
PHASE I : EOR Database Investigation & Evaluation	Update 1 to Team advisor	9-Oct	Start Pt.
	Review data package & state objectives	17-Oct	1
	Develop Interim Design Review	16-Oct	1
	Begin High Level Data Investigation	24-Oct	1
	Literature Review - EOR Screening	21-Nov	5
	Team Assignments & Completion Schedule	21-Oct	1
	Update 2 to Team advisor	23-Oct	1
	Sort data package into basins	31-Oct	1
	Eliminate outliers	31-Oct	1
	Update 3 to Team advisor	6-Nov	1
	First Initial Final Design	11-Nov	1
	Present First Initial Final Design	14-Nov	1
	Determine average reservoir properties by field	7-Nov	1
PHASE II : Field EOR Ranking	Determine applicable EOR methods for fields	14-Nov	1
	Develop scorecard criteria/categories	14-Nov	1
	Update 4 to Team advisor	20-Nov	1
	Assign scores to the field-EOR combinations	21-Nov	1
	Review rankings	21-Nov	1
	Select top 10 paired field-EOR methods	21-Nov	1
	Practice Presentation, Final Design	30-Nov	1
	Final Design (Fall Semester)	7-Dec	4
	Final Design Presentation (Fall Semester)	9-Dec	3
PHASE III : Establishing & Modeling Top Candidates	FINALS WEEK & WINTER BREAK	23-Jan	6
	Update Workflow and Gantt Chart	8-Feb	2
	Develop Production models for top 10 Field-EOR	4-Apr	7
	Progress Report 1 (Written Report & Presentation)	29-Feb	3
	Apply Economic analysis for top 10 Field-EOR	8-Apr	5
	Re-rank & Select Top 5	9-Apr	2
	Progress Report 2 (Written Report & Peer Review)	28-Mar	3
	Progress Report 3 (Final Draft & Presentation)	18-Apr	3
	Final Report Presentation	30-Apr	2
	Final Project Report Due	6-May	2